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Verification of Aerial Photo Stand Volume Tables for Southeast Alaska

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Abstract

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Aerial photo volume tables are used in the multilevel sampling system of Alaska Forest Inventory and Analysis. These volume tables are presented with a description of the data base and methods used to construct the tables. Volume estimates compiled from the aerial photo stand volume tables and associated ground-measured values are compared and evaluated.

Keywords: Remote sensing, aerial stand volume table, volume, southeast Alaska.

Research Summary

Aerial photo stand volume tables were developed with existing Forest Inventory and Analysis data. Methods used to construct the tables are described. Volume estimates compiled from aerial photo stand volume tables and associated ground-measured volumes are compared and evaluated. Two photo interpreters independently compiled a total volume estimate for 21 plots. Both estimates were within less than 5 percent of the ground-measured volume.

Contents

Introduction

Forest Inventory and Analysis (FIA) work units, such as the Anchorage unit of the Pacific Northwest Research Station, are challenged with taking and keeping current inventories of renewable forest and rangeland resources. Early inventories were mostly oriented toward timber. Now they account for all renewable resources, although many still focus on timber. Southeast Alaska has about 6 million acres of timberland. Assessing the renewable resources of this large, mostly inaccessible area and an additional 5 million acres of rangeland (Hutchison 1967) requires use of cost-effective measures more than ever as inventory funds are allocated to a variety of resources.

With this in mind, Alaska's FIA group has developed and is testing a multilevel sampling system designed to gather biological and physical information that will provide a basis for national, regional, and local renewable resource analyses. Several remote sensing levels are included in this system because of the high probability that one or more will be cost effective.

Good timber volume estimates are historically and continually an important objective of many forest inventories. With the advent of multiresource inventories, this objective has become more difficult to achieve because the number of ground-measured timberland locations has been reduced to accommodate inventory of other resources. Reliable aerial photo volume estimates can be used to augment ground measurements and decrease volume sampling error.

Localized aerial photo volume tables can be expected to provide stand volume estimates similar to ground estimates. For this reason, the Alaska Integrated Resource Inventory System needs localized aerial tables. Improved volume figures would also be a boon to supplying Alaska's input to national and local timber assessments; therefore, we developed four aerial photo stand volume tables specifically for forest types in southeast Alaska.

Literature Review

Use of aerial photographs to estimate timber volumes was first tested in Germany (Spurr 1952). A number of photo volume tables for various species were subsequently developed in the United States (Pope 1950, Moessner and others 1951, Mead and Setzer 1984). These fall into two major types: single-tree volume tables and stand volume tables (Heller and Ulliman 1983). Stand volume tables were deemed most applicable to Alaska's extensive forest inventory. The literature shows relative agreement that volume is best correlated with height and crown closure, although some investigators have also included tree count and crown diameter (Heller and Ulliman 1983). The actual form of a particular volume equation seems to vary widely by species and locality. Among the combined and transformed variables other researchers have found to improve their regression estimates are height and closure raised to the second power (Moessner 1963); height, crown diameter, and the product of height and crown diameter (Bonner 1966); and height and the product of height and crown closure (Edminster and Getter 1979). In fact, previous research by Sayn-Wittgenstein and Aldred (1967) showed that every tree species they tested required a different equation and combination of variables to yield the lowest possible standard errors (Heller and Ulliman 1983).

In previous Alaska aerial stand volume equations, closure raised to the second power and the product of closure and height were used as predictor variables for interior Alaska spruce. For hardwoods, the product of closure and height as well as closure times height raised to the second power yielded the best equation (Haack 1963a). This research also shows highest correlation with the five tallest tree heights rather than average tree height.

All studies used forms of multiple regression techniques to build equations and tables. Most used ordinary least-squares regression (Edminster and Getter 1979, Haack 1963a, Tiwari and Parthasarthy 1979).

Methods

The Data Set

We used existing data in FIA files because we lacked project funds to collect data specifically for aerial volume tables. The data set evaluated for this study was collected in the 1970's from five southeast Alaska inventory units: Juneau, Ketchikan, Petersburg-Wrangell, Prince of Wales, and Sitka. The original photo plots were systematically distributed over 1:15,840 scale black-and-white aerial photographs. The data available for volume table construction came from 962 ground-measured locations selected at random from 66,731 photo points. All points were located in timberland. A number of forest types and a wide range of stand conditions were represented. Seedling- and sapling-size stands were eliminated from the data set because residual trees in these cutover stands had widely varying volumes. Additional plots were deleted because aerial photos or data elements such as crown closure and tree height were missing. The total usable sample was 864 plots randomly located on timberland throughout southeast Alaska.

Stand Height

Variations in photo-height estimates can be expected among different interpreters because of interpreter bias and systematic error (Gingrich and Meyer 1955). For these reasons, we used ground-measured heights, which are less subject to this type of error. The data base we used for this work included height measurements for all trees 5 inches and larger. The five tallest ground-measured tree heights were averaged and used as the basis for our predictive equations. Previous studies by Gingrich and Meyer (1955), Haack (1963a), and Joshi (1973) have shown better correlation with the three to five tallest tree heights than with average stand height.

Crown Closure

Crown closure was measured on circular 1-acre plots in one forest type surrounding the photo points. In some cases, this meant shifting plots so that the entire circle fell in the same forest type as the pinpricked photo point. Ground-measurement points had also been shifted to stay in one forest type. Closure was determined by comparing photo observations with crown-density scales graduated in 10-percent classes and interpolated to the nearest 5 percent.

Volume

The ground volumes that were compared with the aerial photo volume estimates were compiled with equations for gross cubic-foot volumes, from ground measurements of diameter, height, and number of trees per acre. The equations are shown in the following publications: hemlock and Sitka spruce (Haack 1963b); western hemlock and Sitka spruce (Embry and Haack 1965); western hemlock and Sitka spruce (Bones 1968); western redcedar and Alaska-cedar (Farr and LaBau 1971); and western hemlock and Sitka spruce (Farr and LaBau 1976).

Aerial photo volume tables were produced for three major softwood forest types or combined types (tables 1-4): (1) Sitka spruce; (2) spruce-hemlock, western hemlock, and mountain hemlock; and (3) Alaska-cedar. Because forest types on aerial photography are often difficult to distinguish, a table was also developed for the above softwood types combined and including western redcedar.

Table 1—Aerial photo volume table for Sitka spruce type in southeast Alaska

Height[1]	Crown closure (percent)[2]										Number of plots[3]
	5	15	25	35	45	55	65	75	85	95	
Feet	*Gross cubic feet per acre*[4]										
40	238	768	1297	1827	2357	2887	3416	3946	4476	5006	1
50	811	1341	1871	2401	2930	3460	3990	4520	5050	5579	0
60	1385	1915	2445	2974	3504	4034	4564	5093	5623	6153	4
70	1959	2489	3018	3548	4078	4608	5137	5667	6197	6727	7
80	2533	3062	3592	4122	4652	5181	5711	6241	6771	7300	2
90	3106	3636	4166	4696	5225	5755	6285	6815	7344	7874	8
100	3680	4210	4739	5269	5799	6329	6859	7388	7918	8448	6
110	4254	4783	5313	5843	6373	6902	7432	7962	8492	9021	10
120	4827	5357	5887	6417	6946	7476	8006	8536	9065	9595	4
130	5401	5931	6461	6990	7520	8050	8580	9109	9639	10170	10
140	5975	6505	7034	7564	8094	8624	9153	9683	10210	10740	3
150	6548	7078	7608	8138	8668	9197	9727	10260	10790	11320	6
160	7122	7652	8182	8711	9241	9771	10300	10830	11360	11890	2
170	7696	8226	8755	9285	9815	10340	10870	11400	11930	12460	1
180	8270	8799	9329	9859	10390	10920	11450	11980	12510	13040	2
190	8843	9373	9903	10430	10960	11490	12020	12550	13080	13610	0
200	9417	9947	10480	11010	11540	12070	12600	13130	13660	14180	1
210	9991	10520	11050	11580	12110	12640	13170	13700	14230	14760	0
220	10560	11090	11620	12150	12680	13210	13740	14270	14800	15330	2

[1] Average height (H) in feet of 5 tallest softwoods.
[2] Crown closure (C) of all overstory from 10 percent crown density scales.
[3] Data obtained from 69 ground plots in southeast Alaska. Lines around numbers show cells for observations used to develop the equation. Other cells were extrapolated from the equation.
[4] Gross volume per acre (inside bark, from 1-foot stump to 4.0-inch top) for all live trees at least 5.0 inches in d.b.h. Volumes obtained from weighted regression equation:

$$V = -2321.96 + \underset{(7.711)}{57.3703}\,H + \underset{(3.649)}{52.9761}\,C.$$

The t-statistic of coefficients is shown in parentheses.
Standard error of estimate around mean volume = 30.8 percent. $R^2 = 0.53$.

Table 2—Aerial photo volume table for spruce-hemlock, western hemlock, and mountain hemlock types combined in southeast Alaska

Height[1]	Crown closure (percent)[2]										Number of plots[3]
	5	15	25	35	45	55	65	75	85	95	
Feet	*Gross cubic feet per acre* [4]										
30	6	450	904	1338	1783	2227	2671	3115	3560	4004	1
40	718	1162	1606	2050	2495	2939	3383	3827	4272	4716	10
50	1429	1874	2318	2762	3206	3651	4095	4539	4983	5428	21
60	2142	2586	3030	3474	3918	4362	4807	5251	5695	6139	42
70	2853	3297	3742	4186	4630	5074	5519	5963	6407	6851	70
80	3565	4009	4453	4898	5342	5786	6230	6675	7119	7563	87
90	4277	4721	5165	5610	6054	6498	6942	7387	7831	8275	77
100	4277	5433	5877	6321	6766	7210	7654	8098	8543	8987	78
110	5700	6145	6589	7033	7477	7922	8366	8810	9254	9699	91
120	6412	6857	7301	7745	8189	8634	9078	9522	9966	10410	69
130	7124	7568	8013	8457	8901	9345	9790	10230	10680	11120	54
140	7836	8280	8724	9169	9613	10060	10500	10950	11390	11830	26
150	8548	8992	9436	9881	10320	10770	11210	11660	12100	12550	10
160	9260	9704	10150	10590	11040	11480	11930	12370	12810	13260	12
170	9972	10420	10860	11300	11750	12190	12640	13080	13530	13970	12
180	10680	11130	11570	12020	12460	12900	13350	13790	14240	14680	2

[1] Average height (H) in feet of 5 tallest softwoods.
[2] Crown closure (C) of all overstory from 10 percent crown density scales.
[3] Data obtained from 662 ground plots in southeast Alaska. Lines around numbers show cells for observations used to develop the equation. Other cells were extrapolated from the equation.
[4] Gross volume per acre (inside bark, from 1-foot stump to 4.0-inch top) for all live trees at least 5.0 inches in d.b.h. Volumes obtained from weighted regression equation:

$$V = -2351.99 + \underset{(23.143)}{71.1847\,H} + \underset{(6.971)}{44.4251\,C}.$$

The t-statistic of coefficients is shown in parentheses.
Standard error of estimate around mean volume = 28.9 percent. $R^2 = 0.48$.

Table 3—Aerial photo volume table for Alaska-cedar type in southeast Alaska

Height[1]	Crown closure (percent)[2]										Number of plots[3]
	5	15	25	35	45	55	65	75	85	95	
Feet	*Gross cubic feet per acre*[4]										
40	172	542	912	1283	1653	2023	2393	2763	3133	3503	1
50	1384	1755	2125	2495	2865	3235	3605	3975	4345	4715	9
60	2597	2967	3337	3707	4077	4447	4817	5187	5558	5928	17
70	3809	4179	4549	4919	5289	5660	6030	6400	6770	7140	14
80	5021	5391	5761	6132	6502	6872	7242	7612	7982	8352	11
90	6234	6604	6974	7344	7714	8084	8454	8824	9194	9565	5
100	7446	7816	8186	8556	8926	9296	9666	10040	10410	10780	4
110	8658	9028	9398	9768	10140	10510	10880	11250	11620	11990	4
120	9870	10240	10610	10980	11350	11720	12090	12460	12830	13200	1
130	11080	11450	11820	12190	12560	12930	13300	13670	14040	14410	0

[1] Average height (H) in feet of 5 tallest softwoods.
[2] Crown closure (C) of all overstory from 10 percent crown density scales.
[3] Data obtained from 66 ground plots in southeast Alaska. Lines around numbers show cells for observations used to develop the equation. Other cells were extrapolated from the equation.
[4] Gross volume per acre (inside bark, from 1-foot stump to 4.0-inch top) for all live trees at least 5.0 inches in d.b.h. Volumes obtained from weighted regression equation:

$$V = -4861.91 + \underset{(8.044)}{121.23\,H} + \underset{(1.631)}{37.01\,C}.$$

The t-statistic of coefficients is shown in parentheses.
Standard error of estimate around mean volume = 32.3 percent. $R^2 = 0.55$.

Table 4—Aerial photo volume table for all softwood types combined in southeast Alaska

Height[1]	Crown closure (percent)[2]										Number of plots[3]
	5	15	25	35	45	55	65	75	85	95	
Feet	*Gross cubic feet per acre*[4]										
30	422	841	1259	1677	2096	2514	2932	3351	3769	4187	2
40	1089	1508	1926	2344	2763	3181	3599	4018	4436	4854	13
50	1757	2175	2593	3012	3430	3848	4267	4685	5103	5522	38
60	2424	2842	3260	3679	4097	4515	4934	5352	5770	6189	73
70	3091	3509	3927	4346	4764	5182	5601	6019	6437	6856	103
80	3758	4176	4595	5013	5431	5850	6268	6686	7105	7523	113
90	4425	4843	5262	5680	6098	6517	6935	7353	7772	8190	103
100	5092	5511	5929	6347	6766	7184	7602	8021	8439	8857	92
110	5759	6178	6596	7014	7433	7851	8269	8688	9106	9524	107
120	6427	6845	7263	7682	8100	8518	8937	9355	9773	10190	76
130	7094	7512	7930	8349	8767	9185	9604	10020	10440	10860	65
140	7761	8179	8598	9016	9434	9853	10270	10690	11110	11530	29
150	8428	8846	9265	9683	10100	10520	10940	11360	11770	12190	16
160	9095	9513	9932	10350	10770	11190	11610	12020	12440	12860	14
170	9762	10180	10600	11020	11440	11850	12270	12690	13110	13530	13
180	10430	10850	11270	11680	12100	12520	12940	13360	13780	14190	4
190	11100	11510	11930	12350	12770	13190	13610	14020	14440	14860	0
200	11760	12180	12600	13020	13440	13860	14270	14690	15110	15530	1
210	12430	12850	13270	13690	14100	14520	14940	15360	15780	16200	0
220	13100	13520	13930	14350	14770	15190	15610	16030	16440	16860	2

[1] Average height (H) in feet of 5 tallest softwoods.
[2] Crown closure (C) of all overstory from 10 percent crown density scales.
[3] Data obtained from 864 ground plots in southeast Alaska. Lines around numbers show cells for observations used to develop the equation. Other cells were extrapolated from the equation.
[4] Gross volume per acre (inside bark, from 1-foot stump to 4.0-inch top) for all live trees at least 5.0 inches in d.b.h. Volumes obtained from weighted regression equation:

$$V = -1788.4066 + \underset{(26.276)}{66.7148}\,H + \underset{(8.003)}{41.8336}\,C.$$

The t-statistic for coefficients is shown in parentheses.
Standard error of estimate around mean volume = 29.2 percent. $R^2 = 0.46$.

Regression Analysis

Data were first described and checked with Biomedical Programs (BMDP) (University of California, Los Angeles 1983) statistical software. Minimum and maximum values for each variable were shown for each forest-type grouping. Means, medians, modes, and standard deviations were calculated for height, closure, and volume. Questionable outliers were checked for possible recording errors. Seedling and sapling stand-size plots were dropped because of the wide variation in volumes resulting from occasional residual trees. An examination of the independent variables plotted against the volume determined that a linear relationship fit as well as any other and that linear regression would be an appropriate procedure (figs. 1-4). Literature review revealed which variables and transformations had been used successfully in other stand volume tables. Regressions were then run, again with BMDP software; height, crown closure, and various transformations were used as independent variables. Several transformations of the original variables gave improved estimates for some species; however, we decided to use the basic untransformed variables for all equations to provide uniform, comparable tables for all forest types. Regression lines for all forest types were compared with one another for significant differences with F-tests on intercepts and slopes. On this basis, western hemlock, mixed spruce-hemlock, and mountain hemlock forest types were grouped together. Alaska-cedar and Sitka spruce were different enough from this grouping to justify construction of separate tables for each of these types. Western redcedar data showed extremely poor correlations with the dependent variable, volume, so no table was constructed for this forest type. Western redcedar data (67 plots) were included in construction of the combined table, and we recommend that this general table be used to determine volumes for the western redcedar type. Ordinary least-squares regression, which assumes equal variances throughout the range of the dependent variable, was used to develop an unbiased estimator. This may have given us an estimator with a larger variance than if a weighted procedure (Neter and Wasserman 1974) had been used, but ordinary least-squares regression is a procedure commonly used in the aerial stand volume literature. A standard error of 29.2 percent of mean cubic-foot volume was obtained for the final general model (all softwood types combined) data. The R^2 and standard errors are shown as footnotes in tables 1-4. Predicted and observed volumes for the final equations are shown in figures 1-4.

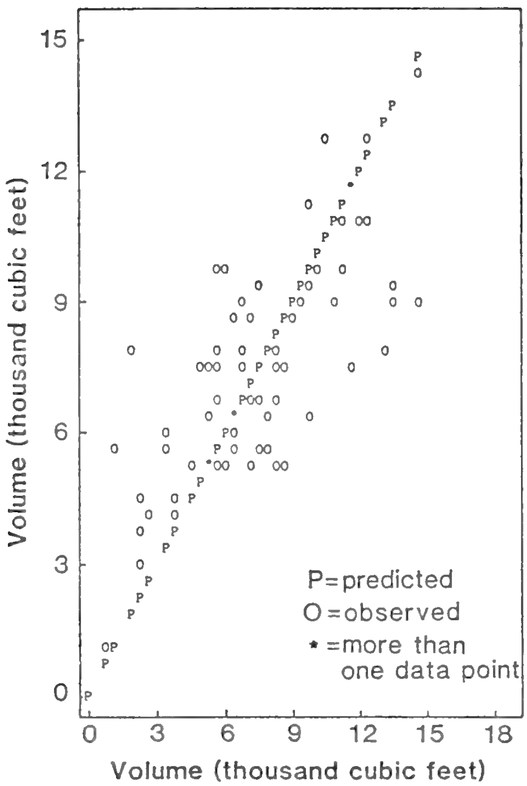

Figure 1—Predicted and observed volumes for Sitka spruce type.

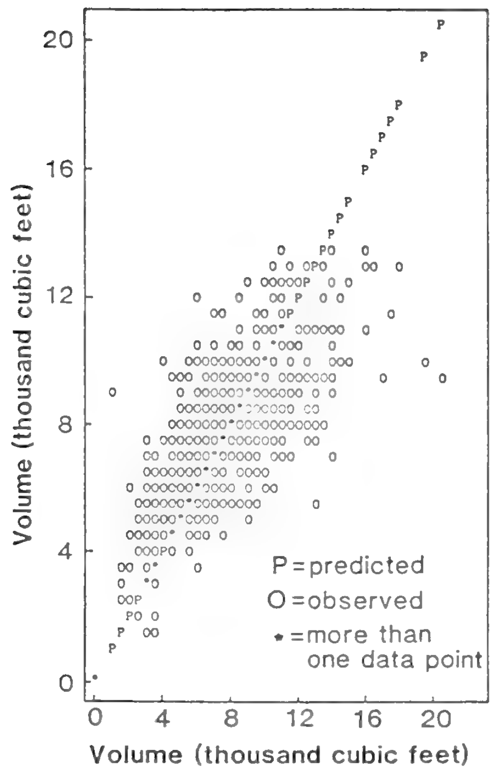

Figure 2—Predicted and observed volumes for spruce-hemlock and hemlock types.

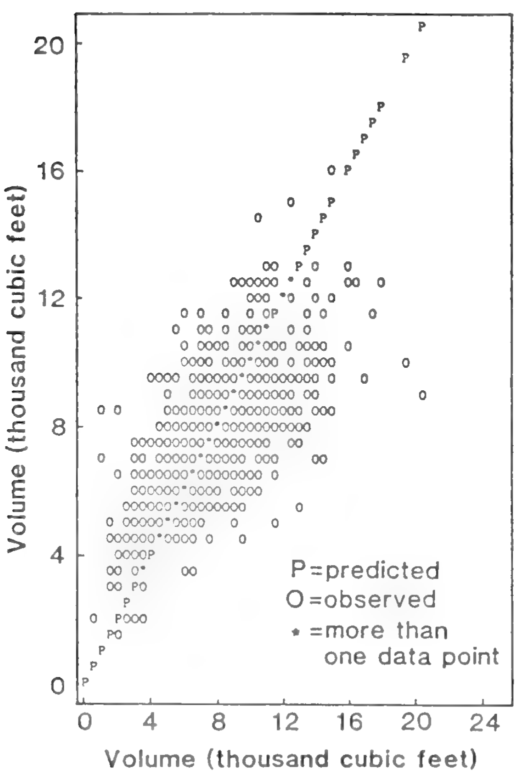

Figure 3—Predicted and observed volumes for Alaska-cedar type.

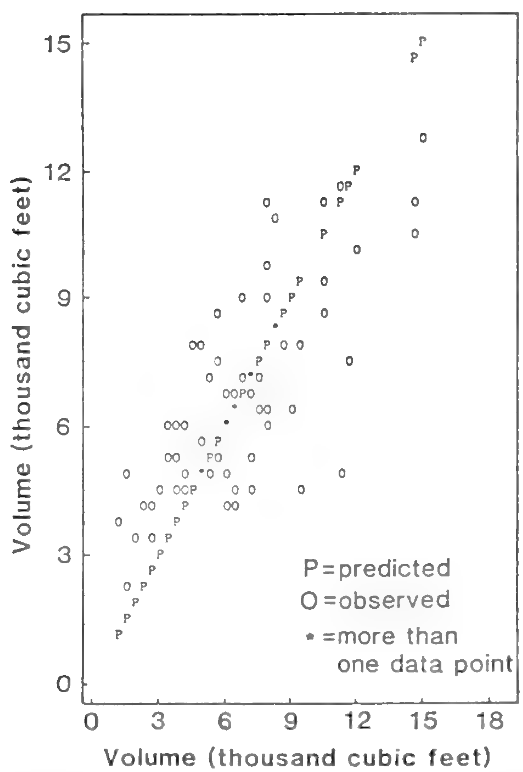

Figure 4—Predicted and observed volumes for all softwood types combined.

Results

Verification

Using all the volume tables, we conducted a test to help determine the validity of the equations that were used to build these tables. First, a random sample of plots was selected from the nearly 900 plots available to develop table values. This sample was set aside for the verification test and was not used in developing the equations. The number of plots drawn was deemed large enough to assure eight or more plots in each of three forest types. Some of the plots drawn were discarded, however, because of inadequate stereo coverage, leaving 21 plots to be measured for the test.

Two photo interpreters, PI_1 and PI_2, independently measured heights and crown closures on the 21 plots. Later, these values, which were not calibrated and adjusted to ground measurements, were entries in the aerial stand volume tables. Associated volumes were totaled and compared with the total ground volume for all 21 plots, all softwood types combined, as well as for the other three forest-type tables. In the following tabulation are the volume totals that were independently estimated by each interpreter for the different forest types and the total ground volume for each type:

		Volume		
	Plots	Photo interpreter 1	Ground-measured	Photo interpreter 2
	(Number)		(Cubic feet)	
Sitka spruce (table 1)	5	34,029	33,328	34,865
All softwood types combined (table 4)[1]	5	36,517	33,328	38,678
Spruce-hemlock, western hemlock, and mountain hemlock (table 2)	9	59,178	70,596	67,993
All softwood types combined (table 4)[1]	9	59,349	70,596	67,595
Alaska-cedar (table 3)	5	33,008	27,169	29,305
All softwood types combined (table 4)[1]	5	31,938	27,169	27,755
Total, tables 1, 2, 3	19	126,215	131,093	132,163
Total, table 4[1]	19	127,804	131,093	137,742

[1] Total for this tabulation and the number of plots do not include western redcedar data.

Table 5 shows a comparison of total estimated volumes of the different forest-type aerial photo volume tables, the all-softwood-types-combined volume table, and total ground-measured volumes.

Table 5—Predicted and ground-measured cubic-foot volumes for southeast Alaska by aerial photo volume tables, mean absolute percentage error (MAPE), and root mean square difference (RMSD)[1]

Aerial volume table	Number of plots	Measured ground volume	Photo interpreter 1		Photo interpreter 2	
			Predicted volume	Percent from ground	Predicted volume	Percent from ground
Sitka spruce						
(table 1)	5	33,328	34,029	+2.1	34,865	+4.6
MAPE			24.5		19.9	
RMSD			1,805	1,360		
Spruce-hemlock, western hemlock, and mountain hemlock						
(table 2)	9	70,596	59,178	-16.2	67,993	-3.7
MAPE			33.2		17.9	
RMSD			2,948		1,717	
Alaska-cedar						
(table 3)	5	27,169	33,008	+21.5	29,305	+7.9
MAPE			49.6		29.4	
RMSD			2,462		1,751	
All softwood types combined[2]						
(table 4)	21	140,748	139,175	-1.1	147,397	+4.7
MAPE			33.1		25.3	
RMSD			2,360		1,741	

[1] Mean absolute percentage error =

$$\left[\sum_{t=1}^{n} |\text{Ground volume - predicted volume}| / \text{ground volume}\right] / (0.01)(n)$$

(n = number of observations).

Root mean square difference $= \sqrt{\Sigma\,(d_i^2) / N}$;

where d is the difference between ground-measured volume and predicted volume; N is the number of plots (Schmidt 1979). Comparisons of RMSD between interpreters using a single table indicate relative efficiencies. Comparisons of RMSD between tables are not meaningful.

[2] All softwood types from tables 1, 2, and 3 and western redcedar.

Discussion

The southeast Alaska inventory area includes almost 21 million acres. The estimated forest-land area is 11 million acres, of which about 6 million acres are timberland. The four most important forest types (in both area and volume) are western hemlock, mountain hemlock, western hemlock-Sitka spruce, and Sitka spruce. The Alaska-cedar type is also important because of the high value of Alaska-cedar products.

Alaska Integrated Resource Inventory System ground plots, not all of which are on timberland, were established and measured at about 235 large-scale aerial photo locations during 1985 and 1986. Volumes for these locations will be predicted with the tables developed here. This will add additional volume stratum information to the ground-sampling phase and also should reduce the error of volume estimates.

When measuring tree height from photos, individual interpreter's biases may cause additional systematic error when they use the tables we produced. A calibration study should be performed to compare and adjust heights measured by each photo interpreter with heights measured on the ground; consistency of crown-closure measurements must also be maintained among all interpreters. The tables also depend on the accuracy and confidence limits of the original local volume tables used to determine ground-plot volumes.

Users of the volume tables or equations presented here are cautioned to observe their limitations. They are intended as photo-volume equations for southeast Alaska. Before these equations are applied to measurements for other forest types and scales of photography, a user should conduct validation tests for the other types and scales.

Common and Scientific Names of Trees

Common name	Scientific name[2]
Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western redcedar	*Thuja plicata* Donn

[2] Scientific names are according to Viereck and Little (1972).

Metric Equivalents

1 foot = 0.3048 meter
1 acre = 0.4047 hectare
1 cubic foot = 0.0283 cubic meter
1 cubic foot per acre = 0.069 97 cubic meter per hectare

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Aerial photo volume tables are used in the multilevel sampling system of Alaska Forest Inventory and Analysis. These volume tables are presented with a description of the data base and methods used to construct the tables. Volume estimates compiled from the aerial photo stand volume tables and associated ground-measured values are compared and evaluated.

Keywords: Remote sensing, aerial stand volume table, volume, southeast Alaska.

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